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ScienceDirect
Renewable and Sustainable Energy Reviews 13 (2009) 201–207
RENEWABLE & SUSTAINABLE ENERGY REVIEWS
www.elsevier.com/locate/rser

Current situation of the wind energy use and investigation of wind resources in the coastal region of the Baltic Sea in Lithuania

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Received 29 May 2007; accepted 21 June 2007

Abstract

In this paper current situation and future prospects of the use of wind energy and wind power resource assessment experience in Lithuania are reviewed. Installed wind power capacity has increased from 6.4 to 54.84 MW in Lithuania in 2006. During last five years wind power resource assessment was carried out, wind measurements were generalized and on the basis of obtained results Lithuanian wind resources map was developed. Measurements have shown that the most suitable region for building WT of big capacity is the 10 km wide coastal strip in Lithuania. The suitability of several existing WT sites was evaluated by the power output coefficient, which describes the efficiency of installed WT. The aim of this work is to present the current situation of wind energy development and the results of the investigation of wind climate conditions in the coastal region of the Baltic Sea in Lithuania.

Keywords: Wind resources; Wind turbines; Power output; Efficiency

Contents

1. Introduction

The successful wind energy development clearly reflects the political priority that the leading countries are giving to wind energy by creating favorable frameworks. In 2005 the countries with the highest total installed capacity were Germany (18,428 MW), Spain (10,027 MW), the USA (9,149 MW), India (4,430 MW) and Denmark (3,122 MW) [1–3]. India has thereby overtaken Denmark as the fourth largest wind market in the world. A number of other countries, including Portugal, Italy, the UK, the Netherlands, Japan, China, have reached the 1000 MW mark of installed capacity. Wind energy continued its dynamic growth worldwide in the year 2006. At the end of the last year the worldwide capacity was 73.9 GW. The currently installed wind power capacity generates more than 1% of the global electricity consumption. Based on the accelerated development, World Wind Energy Association has increased its prediction for 2010 and expects now 160,000 MW to be installed by the end of 2010 [1].

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1364-0321/$ - see front matter
doi:10.1016/j.rser.2007.06.012

The national wind energy programs of different countries are the basis for the increase of the wind energy use. These programs are directed toward the evaluation and investigation of climate conditions of the country, promotion of modern wind power technologies and development of the policies to facilitate the reaching of the national goals to increase wind power penetration. Many countries (Germany, Australia, the Netherlands, Denmark and others) are linking wind power electricity production to the reduction of fossil fuel consumption [3]. Plans of reaching certain wind power capacity over a certain period have been established by Spain, Italy, Finland, Lithuania and many other countries. Specific plans for offshore wind farms deployment were present in the UK, the Netherlands, Germany, Denmark, etc.

There are four most popular national incentives for wind power development: direct capital investment (subsidies and grants for the projects), establishment of a premium price for wind-generated electricity, obligations for utilities to purchase wind-generated electricity and provision of free (liberalized) market for green electricity. There are more measures for wind power development, which vary in different countries. Because of these effective measures wind energy continues to expand worldwide and wind turbines continue to grow larger.

Complex terrain and special climate conditions caused specific wind turbine design and installation conditions in some countries. For example, Japan has typical standards for a J-class turbine that can withstand typhoon force winds from damage of turbines there. For countries in northern climates, cold weather causes icing, which reduces energy production. Consequently the separate wind turbines must be developed depending on climate conditions of the region, where wind turbines must be installed [3].

The new EWEA scenario shows that by 2030, wind power could be satisfying 22% of Europe's total electricity supply. This is based on the European Commission's baseline assumptions. If the Commission's energy efficiency projections are taken into account, wind could be supplying as much as 30% in 2030. Although only four countries—Denmark, Spain, Germany and Ireland—presently cover more than 5% of their electricity demand by wind energy, the technology has experienced dramatic growth over the last decade. If EU electricity demand develops as projected in its "Combined high renewables and efficiency case", wind energy's share of demand will reach 5.4% in 2010, 15.7% in 2020 and 30.3% in 2030 [4].

There is specific situation in Lithuania and other Baltic countries. The potential market for wind energy technologies is not very large in all Baltic States. Effective exploitation of the wind turbines (further as WT) requires detailed information on wind climate in selected sites. According to the data of meteorological stations the average wind velocity (speed) on the coastal zone of the Baltic Sea in Lithuania is 5–5.5 m/s at 10 m height above ground level. In the middle of Lithuania it reaches only 3.5–4 m/s. Consequently wind energy development was not so attractive for the Lithuanian energy sector. However, regarding the international efforts in climate change control and the limitation of fossil and nuclear resources, it is obvious that the steady growth of commercial wind energy utilization will be continued in the future. After joining the EU Lithuania assumed the commitment to increase the use of renewable energy sources (RES). According to 2001/77/EC Directive on the promotion of electricity produced from RES, Lithuania must increase the share of green electricity to 7% till 2010 [5]. For the promotion of the use of RES the Lithuanian government has accepted some legislations. According to the Law on Energy [6] the use of RES is promoted by the government by giving soft loans and subsidies, setting preferential taxes, etc., which are presented in [7].

Different organizations and separate persons, constructing or planning to construct wind, hydro, biomass power plants or other power generation facilities, working on RES, have applied repeatedly to the National Control Commission for Prices and Energy asking for price reductions or promises for various future allowances. However, according to the Law on Energy, the responsibility for the use of RES is attributed to the Ministry of Economy. On the request of the consumers of RES, their excess energy, generated in the autonomic facilities, should have an access to the electrical network, and they must be paid according to the established prices and tariffs. The Ministry of Economy has determined the order and conditions of their connection to the electrical network. According to the Law on Energy the suppliers must be paid on the contractual prices and tariffs.

A specific feature of the Lithuanian energy sector is considerable surplus of power generation. In 2005 the installed capacity in Lithuania totalled to 4966.4 MW. The largest share was taken by Lithuanian Power Plant (1800 MW), Ignalina Nuclear Power Plant (NPP) (1300 MW) and cogeneration power plants (730 MW). It must be noted that according to Lithuania's commitments to the EU, operation of the first unit (installed capacity 1300 MW) of Ignalina NPP was stopped on the 31 December 2004. In 2005 Ignalina NPP comprised 26% of the installed capacity and generated up to 70% of all electricity in Lithuania. Increasing number of governments worldwide realize the need to utilize local and RES instead of relying on imported fossil and nuclear resources with their high political and economic risks. In the new National energy strategy serious attention is given to renewables for electricity production [8].

2. Current situation of wind energy development in Lithuania

Till 2004 electricity production using RES was produced almost only in hydro power plants in Lithuania. However, further development of this sector is restricted by the environmental requirements. Thus other RES are searched

for energy production. Particular attention is given to wind energy as it has the best development possibilities.

Lithuania has some problems with construction of wind turbine parks, because there is too little free land with good wind conditions for WT installation, and some zones are in the protected areas, where such installations are prohibited. Therefore, only at the beginning of 2004 the first WT of the capacity of 630 kW and the pilot wind farm (capacity 5.4 MW) were constructed near the Baltic Sea in Lithuania. Till now the turbines of this wind farm have not been connected to electrical network because of technical, environmental and other problems.

At the beginning of 2006 total installed capacity amounted to 6.4 MW in Lithuania. At the end of the year 2006 several WT of small capacity and two wind farms with total capacity of 46 MW were constructed and connected to the electrical network, and total installed WT capacity in Lithuania reached 54.84 MW.

The Lithuanian government has assumed the commitment to build 200 MW of wind farms till 2010. It is planned that in 2010 WT will generate 2% of all electricity. The competition for the installation of wind farms in different regions of Lithuania has been announced, because the possibilities of connection of WT to the electrical network must be evaluated. Specialists of the Lithuanian Energy Institute (LEI) have determined criteria for selection of WT construction sites, prepared methodology of WT parks dislocation in Lithuania, carried out technical-economical analysis of WT installation. Such research is important while developing common constructional plans of WT, regulations of safe work and forecasting perspectives of wind energy development. It has been estimated that the threshold, which can not be passed without capital reconstruction of electrical network, is 500 MW of total capacity of WT. If this amount of WT were installed, the annual electricity production from wind power plants would reach 0.9 TWh.

3. Wind measurement results and evaluation of wind power resources

Wind velocity is the most important parameter for evaluation of the wind energy resources. Any choice of WT design must be based on the average wind velocity at the selected WT construction site.

Regular measurements of wind velocities and directions have been performed in Lithuania since 1945 in a number of meteorological stations that are distributed in a fairly regular network over the whole country. The measurements are performed every 3 h and typically at the height of 10 m above the ground level. Wind velocities are also measured in airports, seaports and in some other sites. All readings are averages over specified periods of time. Monthly and annual averages are also determined.

The long-term average wind velocity from 19 meteorological stations for the period of 1961–1990 and annual wind velocity averages for separate years, 1963 and 1987, is given in Fig. 1. It is evident that the long-term wind velocity averages do not differ very much from the averages of separate years. It was determined that with the increase of observation period from 23–27 to 33–34 years calculation bias changed accordingly from 0.08–0.2 to 0.07–0.15 m/s. The variation in long-term monthly wind velocity averages is similar in the different regions of Lithuania (Fig. 2.).

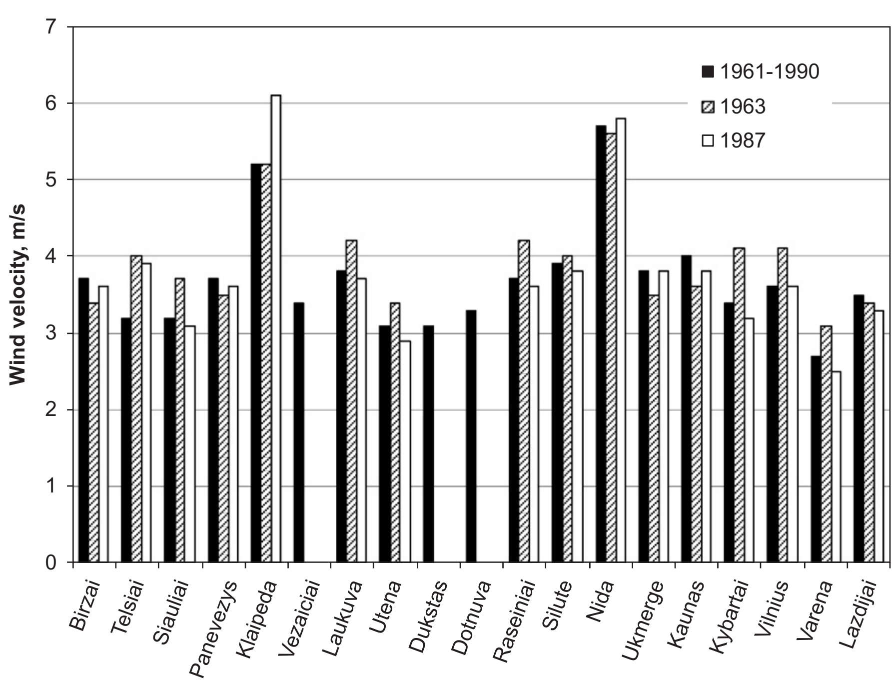

Fig. 1. The average wind velocity in the sites of Lithuanian meteorological stations for different measurement periods.

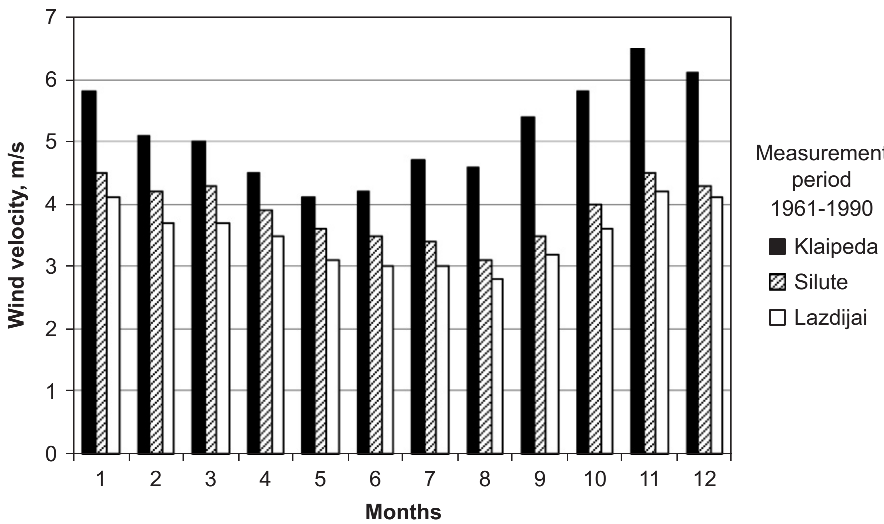

Fig. 2. Variation of average monthly wind velocity in different regions of Lithuania in the period from 1961 to 1990.

The stations are not necessarily located in the best sites for the wind measurements: many of them stand close to living settlements and towns, which contradicts the standard requirements that there should be no buildings, trees or bushes over the radius of 300 m around the site in order to avoid any distortions of the readings. Our survey of meteorological stations in Lithuania revealed that most of them are located on the sites of surface roughness classes 1 and 2, which are described in the European Wind Atlas [9] as open terrains with moderate obstacles. Therefore a certain part of wind velocity readings for specific directions may be underestimated. However, these measurements are very valuable for the estimation of long-term wind velocity averages.

Wind velocity measurements in the territory of Lithuania were also carried out within the project "The Regional Baltic Wind Energy programme" sponsored by the Global Environmental Facility through UNDP [10]. Measurements were performed in the western regions of Lithuania such as Kretinga, Vilkyciai and Taurage where the highest wind resources were expected.

Data gathered by the meteorological stations of Lithuania were analysed in works [11–13]. During the last five-year period wind measurement data were generalized and wind energy resource assessment was carried out. On the basis of obtained results, Lithuanian wind resource map was developed [10,14], which indicates the regions with the highest wind velocities (Fig. 3). It shows that the most suitable region for building large WT (couple of MW) in Lithuania is the 10 km wide coastal strip. In the remaining part of Lithuania the average wind velocity is considerably less than in the coastal region. Nevertheless, there are terrains, where wind velocities may be sufficient for building large capacity WT. Such are the Samogitian Hills, some regions located near Taurage, Raseiniai, Silute and others. However, these regions need more detailed research on wind power resources.

For more precise assessment of wind climate conditions in the coastal region of Lithuania German wind velocity measurement equipment "WICOM-C" was positioned at 1.5 km distance from the Baltic Sea in Giruliai (region of Klaipeda), on the hill of 24 m height above the sea level. Here wind parameters were measured every 10 s, integrated and every 10 min fed into the computer memory. Measurements of wind velocity were carried out at three heights above ground level: 10, 30 and 50 m. Measurements of wind directions were performed at the height of 30 m above ground level with accuracy of 1°.

Wind velocity measurements in Giruliai have shown that wind velocities here are sufficiently high (Fig. 4). Average wind velocity over the period of 1995–2003 at the height of 50 m was 6.4 m/s. Prevailing wind direction is from north-west. We can see that highest wind speeds occur in wintertime and lowest in summertime. The highest average wind velocity was from October to March, while the lowest was observed from April to September. Also measurement data show that highest wind velocities occur from west direction (from the sea) and the lowest from east direction, i.e. from the continental part. Hence, in order to use wind energy most efficiently it is expedient to select WT sites as near the sea as possible.

4. Evaluation of efficiency of installed wind turbines

WT output mostly depends on wind conditions at the site. As a rule, wind velocity and direction vary continuously. Variations in wind velocity occur in the time scale of minutes due to local turbulence, up to several days for typical meteorological structures, and at a scale of months for seasonal variations. The amount of power available from wind varies considerably with wind velocity. Accordingly WT power variations over a certain period of time depend on wind velocity variations, which are

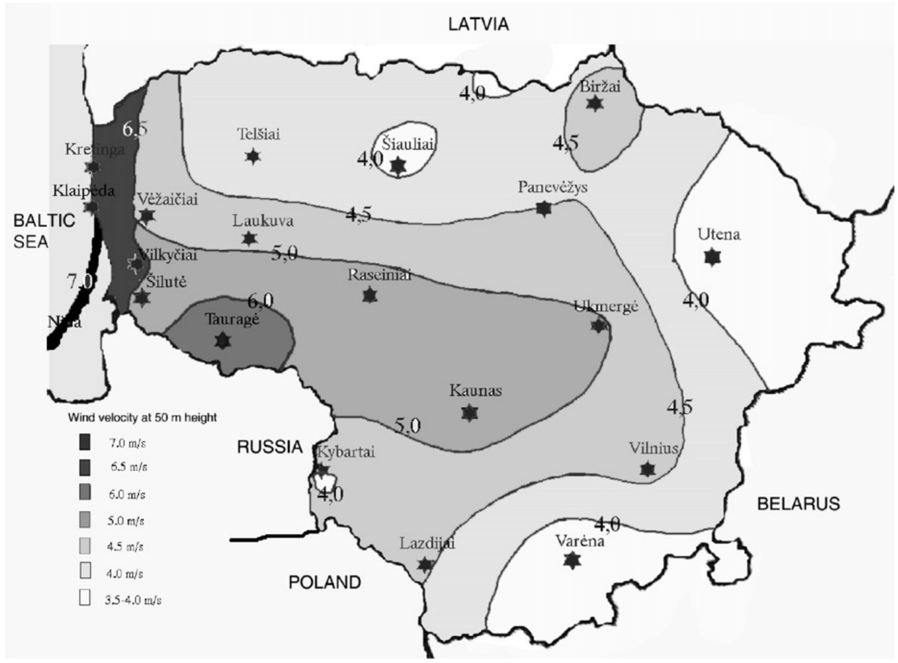

Fig. 3. Distribution of average wind velocity in Lithuania. *—locations of the meteorological stations.

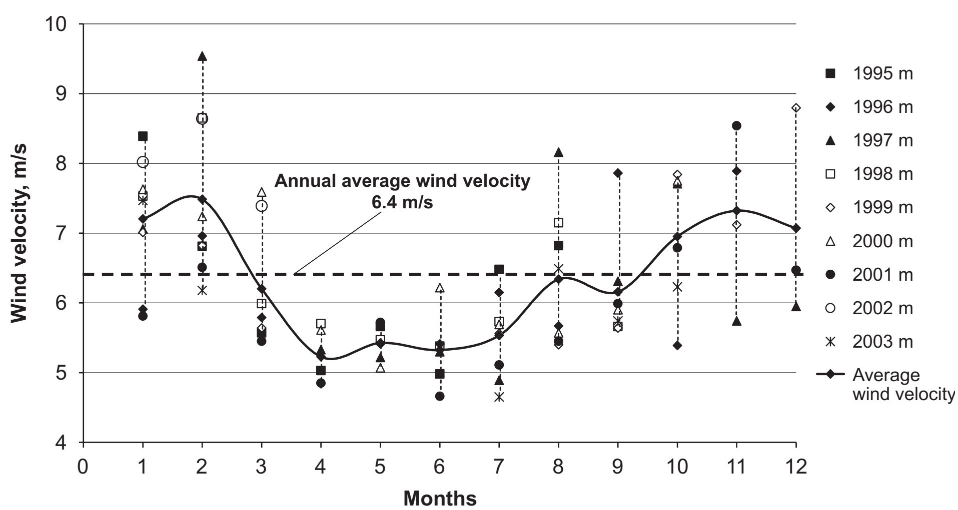

Fig. 4. Annual variation of average monthly wind velocity in Klaipeda region (Giruliai) in Lithuania at the 50 m height above ground level in the period of 1995–2003.

described using a Weibull distribution and density functions [15–17]:

$$F(V) = 1 - \exp\left(-\left(\frac{V}{A}\right)^k\right), \tag{1}$$

$$f(V) = \frac{k}{A}\left(\frac{V}{A}\right)^{k-1} \exp\left(-\left(\frac{V}{A}\right)^k\right), \tag{2}$$

where V is the average wind velocity, A and k are the Weibull parameters, describing the distribution of measured wind velocities. Weibull probability density function is used for wind energy calculation:

$$E = \frac{1}{2}\rho \int_0^\infty f(V)V^3\,\mathrm{d}V, \tag{3}$$

where ρ is air density (kg/m^3).

In order to estimate the output of a certain WT, Weibull parameters must be calculated for the hubheight of that WT. Usually Weibull parameters are calculated from the measurements at the height, which is different from the hubheight of the WT. Assuming that wind velocity probability distribution is the same for the heights h_1 and h_2, links between Weibull parameters (A_{h_1}, k_{h_1}) and

(A_{h_2}, k_{h_2}) at heights h_1 and h_2 are:

$$A_2 = \alpha \cdot A_1^{\beta}, \quad k_2 = \frac{k_1}{\beta}, \tag{4}$$

$$\alpha = \left(\frac{h_2}{h_1}\right)^{B_0}, \quad \beta = 1 + B_1 \ln\left(\frac{h_2}{h_1}\right), \tag{5}$$

where: $B_0 = 0.37$ and $B_1 = -0.088$, which were determined experimentally [17].

Having Weibull distribution parameters A and k we can calculate wind energy at the site at certain height above ground level:

$$E = \frac{\rho}{2} A^3 \Gamma\left(1 + \frac{3}{k}\right) [\mathrm{W/m^2}], \tag{6}$$

where Γ is Euler's gamma function.

This method is used for an approximate evaluation of wind power resources from the measurement data. Fairly exact evaluations of this energy are made over sufficiently long time periods, say, over a year. This method was used for the evaluation of wind climate conditions in WT sites and calculation of expected yearly power output. Weibull parameters A and k in our wind parameters measurement site in Giruliai were calculated using least squares method and are shown in Fig. 5.

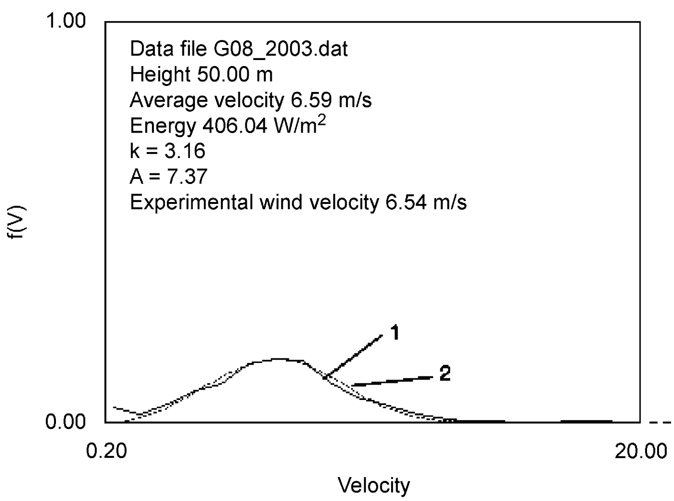

Fig. 5. Weibull distribution of wind velocity variations and estimated parameters k and A at 50 m height above ground level in Klaipeda region (Giruliai). 1—experimental data; 2—approximation by Weibull distribution function.

An analysis of the efficiency of several WT was carried out. During the WT operation time the nominal capacity of WT cannot be fully used because of wind velocity variations. The suitability of WT sites was evaluated by the power output coefficient of WT, which was calculated from the equation following:

$$C_{\mathrm{p}} = \frac{E_{\mathrm{m}}}{E_{\mathrm{om}}}, \tag{7}$$

where E_{m} is the real output of energy of WT in the test site; E_{om} is the potential output of WT, operating at nominal capacity. Data were taken from SC "Lietuvos energija".

The potential monthly output of WT was calculated by

$$E_{\mathrm{om}} = P_{\mathrm{n}} \cdot N_{\mathrm{m}}, \tag{8}$$

where P_{n} is the installed nominal power of WT, N_{m} is number of hours in the month.

The analysis was carried out for the WT located near the Baltic Sea and in the middle of Lithuania. Results are shown in Fig. 6. Calculated power output coefficient of the Vydmantu WT (630 kW, installed near Palanga) was $C_{\mathrm{p}} = 0.265$ for the year 2006, i.e. WT used 26.5% of all installed capacity per year. The power output coefficients for the small WT (160 kW, located near town Skuodas, and 55 kW, located near Kaunas city) were considerably lower. This corresponds to the data in the wind resource map: Vydmantu WT is closest to the sea, so the coefficient is the highest of all three, and power output coefficient of WT near Kaunas city is higher than that of the WT near Skuodas as wind power resources are higher in Kaunas region.

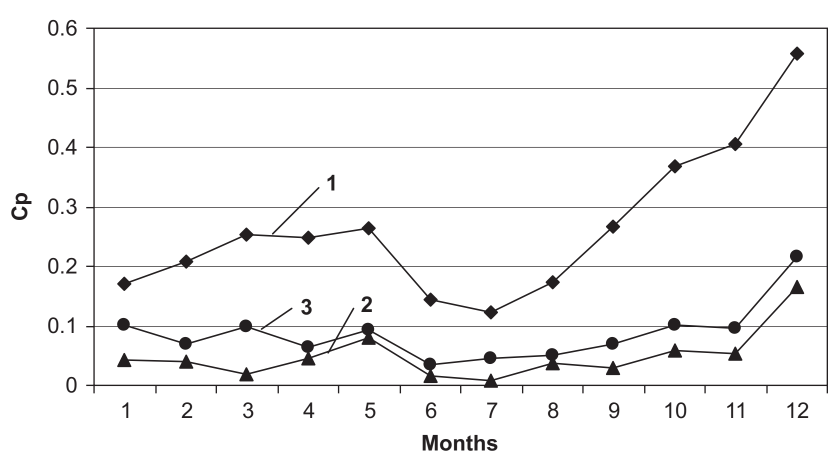

Fig. 6. Annual variation of the power output coefficient C_{p} of installed WT: 1—Vydmantu WT (near the Baltic Sea, town Palanga); 2—small WT near the town Skuodas; 3—small WT in the middle part of Lithuania (near the Kaunas city).

It should be noted that this coefficient depends not only on wind climate conditions at the WT sites. Usually small WT are installed near houses, where surface roughness and nearby obstacles may have significant influence on the wind flow. Worldwide experience shows, that it is possible to use up to 40% of nominal WT capacity and more [18]. According to investigation of wind climate conditions, it is possible to use about 30% of nominal capacity of WT in the Lithuanian Baltic Sea region per year, but the WT output analysis has shown that the WT site selection must be done more thoroughly in Lithuania.

5. Conclusions

Wind energy development has moved a pace forward in Lithuania recently. The capacity of installed WT increased from 6.4 to 54.84 MW in 2006. According to the government decision the capacity of installed WT will comprise 200 MW till 2010.

Analysis of wind power resources has been carried out using annual observation data of Lithuanian meteorological stations and wind measurement data in Klaipeda region. The map of wind resource distribution in Lithuania was developed on the basis of the data obtained, which shows that the best region for wind power development is 10 km wide coastal strip.

LEI wind measurement data in Giruliai were used for more detailed estimation of wind climate conditions in the coastal region of Lithuania. Average wind speed reaches 6.4 m/s at 50 m above ground level in this region.

Method based on Weibull distribution of measured wind velocity was used for the evaluation of wind climate conditions at the sites of the WT.

The analysis of the output of three WT located at different distances from the Baltic Sea was carried out. Average power output coefficient of the Vydmantu WT for the year 2006 was the highest and reached 0.265. The power output coefficients for the small WT were considerably lower and most likely were affected by the topographic conditions of the sites. WT output analysis has shown that the WT site selection must be done more thoroughly in Lithuania.

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